DOI: 10.24850/j-tyca-18-01-02

Articles

Hydraulic analysis of flow in roller spillways and a comparison with linear spillways

Análisis hidráulico del flujo en vertederos de rodillos y comparación con vertederos lineales

Mohammad Reza Farshadi[1], ORCID: https://orcid.org/0009-0009-5446-105X

Mohammad Heidranejad[2], ORCID: https://orcid.org/0000-0002-7306-3614

Amin Bordbar[3], ORCID: https://orcid.org/0000-0001-7632-5766

Alireza Masjedi[4], ORCID: https://orcid.org/0000-0002-2953-3519

Mahdi Asadilor[5], ORCID: https://orcid.org/0000-0002-1065-3895

[1]Department of Water Science Engineering, Ahv.C., Islamic Azad University, Ahvaz, Iran, mohammadreza.farshadi@iau.ir

[2]Department of Water Science Engineering, Ahv.C., Islamic Azad University, Ahvaz, Iran, mo.heidar@iau.ac.ir

[3]Department of Water Science Engineering, Ahv.C., Islamic Azad University, Ahvaz, Iran, borbar500@iau.ac.ir

[4]Department of Water Science Engineering, Ahv.C., Islamic Azad University, Ahvaz, Iran, Al.masjedi@iau.ac.ir

[5]Department of Water Science Engineering, Ahv.C., Islamic Azad University, Ahvaz, Iran, mehdi.asadilour@iau.ac.ir

Author for correspondence: Mohammad Heidarnejad, mo.heidar@iau.ac.ir

Abstract

This study aimed to enhance the performance and efficiency of linear spillways by utilizing a new type of spillway known as Roller spillways. In this model, the structure of the spillway transformed from a simple vertical wall with a linear crest to a cylindrical shape. The goal was to create a linear stream without turbulence over the spillway crest. Two scenarios were examined in this research: the first scenario compared a simple linear spillway with a Roller spillway, while the second scenario assessed the impact of installing a blade on the Roller spillway. The results indicated that the Roller spillway increased the spillway efficiency (discharge coefficient) by up to 70%. Among the models studied, the Roller spillway with a blade demonstrated the best performance, achieving a 30% increase in efficiency without the blade, but with the installation of a blade along the crest (half the length of the crest), it could increase efficiency by up to 70% compared to the linear spillway.

Keywords: hydraulic structures, hydraulic engineering, dams, hydrodynamics, fluid mechanics, measurement.

Resumen

Este estudio tuvo como objetivo mejorar el rendimiento y la eficiencia de los vertederos lineales mediante la utilización de un nuevo tipo de vertedero conocido como vertedero de rodillos. En este modelo, la estructura del vertedero se transformó de una simple pared vertical con una cresta lineal a una forma cilíndrica. El objetivo era crear un flujo lineal sin turbulencias sobre la cresta del vertedero. Se examinaron dos escenarios en esta investigación: el primer escenario comparó un vertedero lineal simple con un vertedero de rodillos, mientras que el segundo escenario evaluó el impacto de la instalación de una cuchilla en el vertedero de rodillos. Los resultados indicaron que el vertedero de rodillos aumentó la eficiencia del vertedero (coeficiente de descarga) hasta en un 70%. Entre los modelos estudiados, el vertedero de rodillos con cuchilla demostró el mejor rendimiento, logrando un aumento del 30% en eficiencia sin la cuchilla, pero con la instalación de una cuchilla a lo largo de la cresta (la mitad de la longitud de la cresta), se podría aumentar la eficiencia hasta en un 70% en comparación con el vertedero lineal.

Palabras clave: estructura hidráulica, ingeniería hidráulica, presa, hidrodinámica, mecánica de fluidos, medición.

Received: 19/01/2026

Accepted: 06/04/2026

Available ahead of print: 11/05/2026

1. Introduction

Spillways are types of hydraulic structures used for the transfer or passage of floodwaters and excess water from the reservoir to the downstream side of dams, serving as a fundamental element in their stability during flood events (Hamidinia et al., 2023). In the networks of irrigation and drainage, also it is possible regulation the level of water, flow rate measurement, and stream control (Saghari et al., 2019). Also, with the sequential construction of spillways the in steep rivers, can reduce the intensity of erosion (Ghasemi Ghasemvand et al., 2024). Since spillways have many uses; therefore, investigating and studying them is of particular importance. Spillway of a dam of dams is actually the ability to counter a dam against events such as floods. The discharge of water from spillways is usually associated with two basic problem, the first is the risk of insufficient discharge capacity and the second is related to the damaging effects of sedimentation, (Gharibvand et al., 2016). Reports of dam failures announced reports show that one-third of these failures occurred due to lack of capacity to discharge the spillways (Derakhshanifard et al., 2023). For this reason, the International Commission on Large Dams has recommended that the spillways of high dams be re-investigated to ensure their safety. Therefore, in orser to design spillway, should consider floods with large return periods, which is to leads to an increase in spillway width and consequently higher construction costs (Gubashi et al., 2024). Non-linear spillways are used to control and pass flow rate required with low flow rate in cases of limited width, to prevent flooding of agricultural lands upstream (Muhamad, 2024). To reduce problems in spillways and valves and as well as to increase their efficiency, they can use combined spillway-orifice structure

(Aghashirmohammadi et al., 2023). The precise distribution and measurement of water in order to reduce losses in irrigation and drainage networks has always been considered. In this direction, spillways and valve, due to having simple relations than the alternative structures, have more application (Iranpour et al., 2024). The presence of suspended and floating materials in water often causes accumulation in the entrance of the valve and upstream of the spillway. This reduces the precision of flow rate measurement (Kumar et al., 2020). Among the studies conducted on spillway-orifice can be referred to the research has been investigated on the performance of ogee spillways by increasing their effective length and by modifying the geometry of the convoluted spillway configuration by creating cuts and slopes along the spillway, they improved its hydraulic performance They used the VOF method to simulate the flow level profile and for the current turbulence model in the softener FLOW-3 D from the turbulence model RNG. Their numerical results showed that in the low Ht/P ratios, modifications in the ogee spillway structure increased the flow rate coefficient of the modified ogee spillways. With the increase in the higher Hr/P ratios, the flow rate coefficient decreased due to the submergence of the ogee spillway (Ghanbari et al., 2020). They also investigated the laboratory and numerical effects of geometric parameters of triangular-trapezoidal ogee spillways on the flow rate coefficient and energy dissipation. In this research, the flow regime was investigated using the VOF method and the RNG turbulence model in the FLOW-3D software for modeling stream turbulence in two different spillway placements in the reservoir. The results of the good performance of numerical software in similar to stream and match the numerical and laboratory results were witness. Also, the flow rate coefficient decreased with increasing the apex angle of the ogee during the stream passing over the apex at high Hr/P ratios. The hydraulic stream over triangular-trapezoidal ogee spillways is free-stream at low flow rate and submerged at high flow rates (Ghanbari et al., 2020). Pashazadeh and colleagues (2016) showed that the combination spillways with valve can be a useful solution for passing floating materials over the spillway and transferring sedimentary materials from under the valve. In this research, the hydraulic properties of different trapezoidal combined spillway-valve models were investigated under three different valve openings at the end of a circular channel. The results showed that the obtained flow rate coefficient correlated well with laboratory results. Razmkah and colleagues (2021) showed that in ogee spillways with a rectangular plan, for a constant upstream water height, the flow rate of the ogee spillway is up to 2.6 times that of a straight spillway, and for a constant flow rate, the upstream water height of the straight spillway is 1.8 times that of the ogee spillway, and they also stated that the best range for Ht/P for designing an ogee spillway that maximizes the discharge coefficient is between 0.2 and 0.4. In a study by Muhamad Bashar et.al (2024), he tried to improve the discharge capacity of inclined spillways by rounding their crests. In this research, twenty-four models of inclined spillways have been tested, in which the inclination angle (a), spillway height (P), and crest diameter (D) were varied. The analysis of the results indicated that the discharge (QOC) increases with an increase in the effective head above the crest (He). The values of the flow rate coefficient (CD) are reduced slightly by increasing values of (He/P) and (He/D), and spillways with smaller inclination angles exhibit lower CD values. An empirical equation was provided to determine CD in terms of He/P, He/D, and a (in radians) with a correlation coefficient of 0.9 and a standard error of 0.01. The highest discharge capacity was obtained from a spillway with a = 20, P = 20 cm, D = 4 cm, and a D/P ratio of 0.2, where the percentage increase in discharge ranged from 147% to 175% compared to a conventional sharp-edged spillway. The results of this study showed that inclined spillways with circular crests have higher discharge capacities compared to some other spillway shapes. Non-linear spillways, due to their increased crest length at a fixed cross-section, lead to an increase in the discharge coefficient compared to linear spillways (Muhamad, 2024). However, non-linear spillways have not gained much attention from operators due to their complexity and high costs; therefore, linear spillways are still utilized in some cases (Ariyanmanesh and Heidarnejad, 2020). In this study, we aim to investigate a new linear spillway known as the Roller Spillway. This spillway model was first used in 2010 at the Roza Dam in the United States, utilizing a circular cylinder as the spillway (Figure 1) (USBR, 2010).

Figure 1. Roller Spillway at Roza Dam, United States. Source: USBR, 2010.

Despite the fact that the primary goal of this structure is to install blades for aquatic passage, the impact of this spillway type and the blades on the hydraulic stream has not been studied until now. Therefore, in this research, we examined the hydraulic conditions and efficiency of this new structure, and to achieve this goal, we simulated the laboratory model of this structure. Experiments were designed to investigate three configurations of this spillway model: in the first case, the Roller spillway without blades, and in the other two cases, blades were installed along the entire crest and half of the Roller spillway crest. Additionally, in the actual model installed at the Roza Dam in the United States, blades are placed in various positions on the Roller spillway, but in this study, they are only installed on the crest of the spillway. In addition to laboratory investigation, this study aims to bridge the gap between experimental findings and practical engineering applications. Previous research has shown that modifying spillway geometry can significantly improve discharge capacity and hydraulic efficiency (Ghanbari et al., 2020; Hamidinia et al., 2023). By analyzing the results using dimensionless parameters, the performance of Roller spillways can be extended to prototype-scale hydraulic structures such as dam spillways and irrigation channels. The outcomes of this research provide insights for improving discharge capacity, reducing construction costs, and enhancing flood safety in real-world conditions (Singh and Kumar, 2022; Derakhshanifard et al., 2023).

2. Materials and Methods

Following the introduction of the geometric and hydraulic parameters affecting the discharge coefficient and energy loss of linear spillways, dimensionless parameters will be extracted using Buckingham's Π theorem. Additionally, the required laboratory equipment for this research will be mentioned, and finally, the procedure for conducting the experiments and the range of variables used will be outlined.

2.1. Dimensional Analysis

In order to achieve the objectives of this research, we will first introduce the parameters governing the hydraulic stream passing through roller spillways, and then the effective governing parameters in this study will be presented as dimensionless relationships. The parameters governing the hydraulic stream in roller spillways are shown in Table 1.

Tecnología y Ciencias del Agua

Table 1. Influential Parameters

Description	Parameter Name	Symbol Parameter
10,15 and 20 cm	Spillway Height	P
60cm	Effective length of the spillway crest in one cycle	L
6.5, 8 and 15 cm	Diameter of Roller Spillway	D
	Wall Thickness of Spillway	T
	Flow Rate	Q
	Water Height Above Spillway Crest	H
	Upstream Velocity	V
	Dynamic Viscosity	µ
	Surface Tension Index	σ
	Specific Weight	P
60cm	Channel Width	L
1,2 and 3 cm	Height of Blade Installed on Roller Spillway	D

Based on Table 1, the effective geometric, kinematic, and dynamic variables in free stream over a linear spillway and roller spillway are represented in Equation (1). Some effective variables are not independent and can be calculated as dependent variables in the following order. In this case, the function for the discharge coefficient of the linear spillway will be represented as Equation (1):

$$f = (L, P, D, T, h, S, Q, V, \mu, \sigma, \rho, W, H) = 0 \quad (1)$$

Using dimensional analysis through Buckingham's π theorem, the following function based on 10 dimensionless variables is obtained:

$$f=\left(\frac{H}{P},\frac{W}{P},\frac{D}{P},\frac{T}{P},\frac{L}{P},\frac{h}{P},\frac{Q}{\sqrt{2gLH^{1.5}}},\frac{\sigma}{\rho V^2 H},\frac{\rho VH}{\mu},\frac{V}{\sqrt{gH}},S\right)=0 \quad (2)$$

In Equation (2), the well-known dimensionless parameters include the Reynolds number Re = $\frac{\rho VH}{\mu}$, Froude number Fr = $\frac{V}{\sqrt{gH}}$, Weber number We = $\frac{\sigma}{\rho V^2 H}$, and the discharge coefficient Cd = $\frac{Q}{\sqrt{2gLH^{1.5}}}$. The minimum Reynolds number in this study is 3500, and the flume slope is zero (S = 0); the effects of Reynolds number and S/H are neglected (Neveen Y. Saad and Ehab M. Fattouh, 2016). Given the constant geometry of the spillway, the final relationship for the dimensionless parameters affecting the discharge coefficient in this research will be as follows:

$$C_d=f\left(\frac{H_t}{P},\frac{D}{P}\right) \quad (3)$$

In Equation (3), Cd is the discharge coefficient for spillways. This parameter is analyzed to evaluate the performance and efficiency of the spillway, and the closer this value is to 1, the better the spillway performance. Therefore, in the rest of the article, the term "efficiency" refers to this value. The equation used to determine the relationship between head and discharge for the spillway is based on the standard discharge equation for sharp-crested spillways (Equation 4):

$$Q=\frac{2}{3}C_d L\sqrt{2g{H_t}^3} \quad (4)$$

In Equation (4), Ht is the total head (the sum of velocity head and hydrostatic head) over the spillway (Singh, D. Kumar, 2022).

2.2. Laboratory Equipment

The experiments in this research were conducted in a flume with walls made of plexiglass, allowing for visibility of the stream inside (Figure 2).

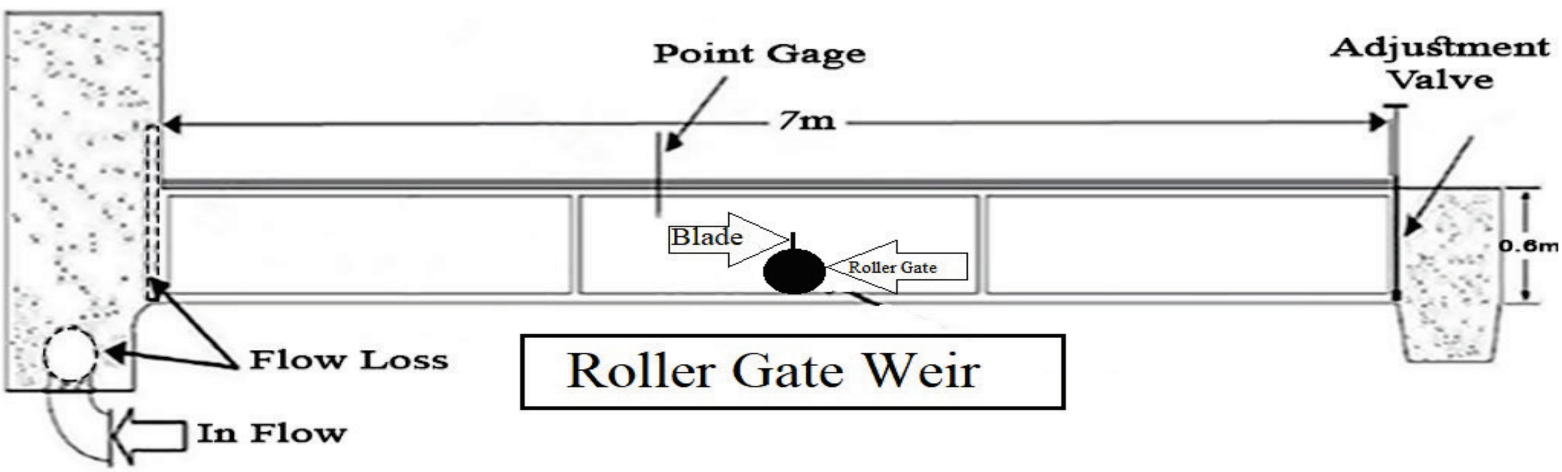


Figure 2. Schematic of the Laboratory Flume

To achieve the objectives of this research and based on the dimensional analysis conducted for the models studied, the variables and experimental models are presented as follows:

a) Control Spillway Experiment: Three heights, 6.5, 10, and 15 cm, with a length of 60 cm (Figure 3a).

b) Roller Spillway Control Experiment: Three heights, 6.5, 10, and 15 cm, with a length of 60 cm (Figures 3b and c).

c) Roller Spillway with Blade: Three blade heights of 1, 2, and 3 cm, and two blade lengths (30 and 60 cm) on the roller spillway (Figure 3c).

The dimensions used above were selected based on the conditions of the laboratory flume.

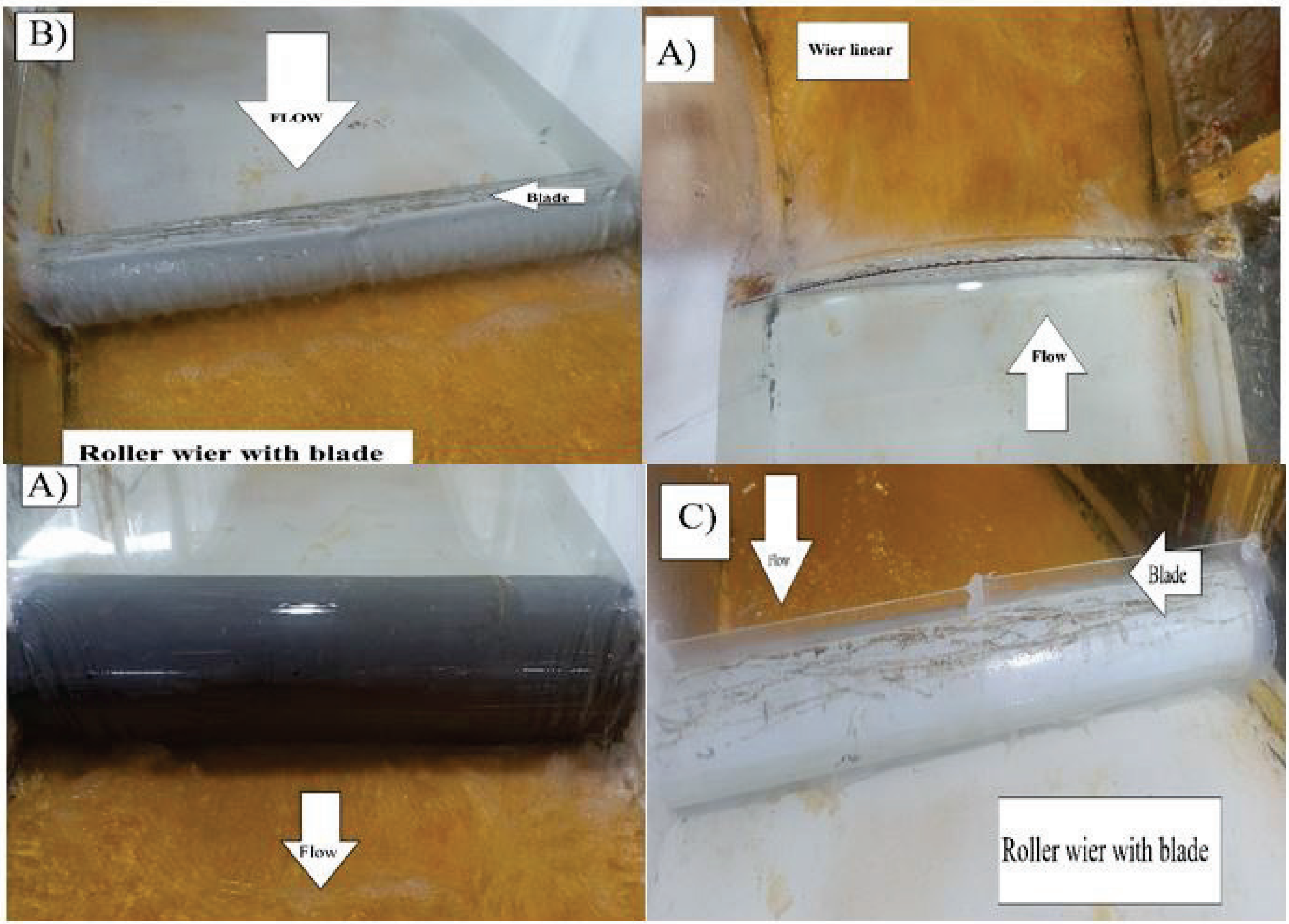


Figure 3. Models of the Spillways and Control Linear Spillway

Initially, to obtain the threshold discharge for submergence, the depth gauge was set at the location for measuring the water height upstream of the spillway (Lu) (indicated by the Point Gage arrow in Figure 2) at the height corresponding to the threshold discharge for submergence. We gradually increased the discharge until the threshold discharge was identified by the water level reaching the set depth gauge. After identifying the threshold discharge of the spillway and considering appropriate ranges and intervals of discharges, five conditions were selected for testing. In each experiment, after ensuring steady stream, the passing flow rate (Q) and the water surface height relative to the spillway crest (h) were directly measured. Generally, the stream profile measurements in all laboratory models included the static stream height upstream of the spillway at an appropriate distance, flow rate readings, and specific surface fluctuations over the spillway. The statistical population of this research consists of the laboratory models of the roller spillway at various discharge data points (samples) (Table 2).

Table 2. Statistical population of this research

Number of Tests	Model Specifications	Flow rate	Number of Models	Spillway Model
30	3 heights 5/6, 8 and 15 cm	10 flow rate	3	Simple Spillway (Control Model)
30	D = 6.5,8, 16 mm	10 flow rate	3	Roller Spillway (Without Blade)
90	H = 1,2,3 cm	10 flow rate	3 (Blade height)	Rolling spillway (with full blade, blade length 60 cm)
90	H = 1,2,3 cm	10 flow rate	3 (Blade height)	Rolling spillway (with half-blade, blade length 30 cm)

In total, regarding geometric and hydraulic considerations, with measurements of ten (10) discharges for each model, a total of 240 tests will be conducted across all models. The hydraulic conditions tested will cover discharges ranging from 10 to 50 liters. This range was chosen based on the scale of the laboratory flume in comparison to first-class channels and dam bodies, which have a scale between 1:200 to 1:1000. Consequently, the selected discharge was also chosen based on this scale, and specific hydraulic conditions were created for each model. After constructing the spillway models, all control models were first tested, followed by experiments on the roller spillway. The procedure for conducting the experiments is as follows: for each test, after installing the spillway and sealing it with aquarium glue, the components related to each experiment are installed on the spillway's outlet slope. Water is then transferred from the water supply tank and pump to the laboratory flumes, and the flow rate is adjusted using a butterfly valve. After that, the water height is measured and recorded at a distance of 40 cm upstream of the spillway and downstream of the spillway. This distance is chosen to ensure readings are taken from a calm and undisturbed area, which enhances measurement accuracy. After data collection from each model, the flow rate is cut off, the roller spillway is removed, and a new model is installed for the next series of experiments. This process is repeated for three spillway heights and three diameters of the roller spillway, resulting in a total of 240 tests.

3. Results Analysis

In this research, we examine roller linear spillways, and the results obtained are analyzed for these spillways. This section's results are discussed in three parts as follows:

1. Effect of Ht/P on the Discharge Coefficient (Cd)
2. Flow rate stage investigation
3. Practical implications of results

First, Table 3 shows the coding of experiments to simplify the graphs.

Table 3. Experiment coding

Experiment cod	**Experiment Name**	**Row**	**Experiment cod**	**Spillway Name**	**Row**
D3h1L60	Roller with a height of 16 with a full blade of 1 cm	13	W1	Simple line with height 5.6	**1**
D3h2L60	Roller with a height of 16 with a full blade of 2 cm	14	W2	Simple line with height 7.10	**2**
D3h3L60	Roller with a height of 16 with a full blade of 3 cm	15	W3	Simple line with height 16	**3**
D1h1L30	Roller with a height of 5.6 with a half blade of 1 cm	16	D1	Roller with height 5.6 without blade	**4**
D1h2L30	Roller with a height of 5.6 with a half blade of 2 cm	17	D2	Roller with height 7.10 without blade	**5**
D1h3L30	Roller with a height of 5.6 with a half blade of 3 cm	18	D3	Roller with height 16 without blade	**6**
D2h1L30	Roller with a height of 7.10 with a half blade of 1 cm	19	D1h1L60	Roller with height 5.6 with full blade 1 cm	**7**
D2h2L30	Roller with a height of 7.10 with a half blade of 2 cm	20	D1h2L60	Roller with height 5.6 with full blade 2 cm	**8**
D2h3L30	Roller with a height of 7.10 with a half blade of 3 cm	21	D1h3L60	Roller with height 5.6 with full blade 3 cm	**9**
D3h1L30	Roller with a height of 16 with a half blade of 1 cm	22	D2h1L60	Roller with height 7.10 with full blade 1 cm	**10**
D3h2L30	Roller with a height of 16 with a half blade of 2 cm	23	D2h2L60	Roller with height 7.10 with full blade 2 cm	**11**
D3h3L30	Roller with a height of 16 with a half blade of 3 cm	24	D2h3L60	Roller with height 7.10 with full blade 3 cm	**12**

Tecnología y Ciencias del Agua

OPEN ACCESS

Check for updates

3.1. Effect of Ht/P on the Discharge Coefficient (Cd)

According to the studies by Afzalian and Ahadian (2016), before complete submergence of the stream, the stream blade is in contact with the side crest, thus surface tension will have an effect. Therefore, the trend of changes in the discharge coefficient relative to the dimensionless parameter Ht/P was examined separately. For this purpose, Figures 4 to 6 analyze the effect of Ht/P on the discharge coefficient (Cd). In these graphs, the horizontal axis represents the dimensionless number Ht/P, which has a direct relationship with the flow rate, indicating that Ht/P is representative of Q. The vertical axis of these graphs shows the dimensionless value of the discharge coefficient (Cd).

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

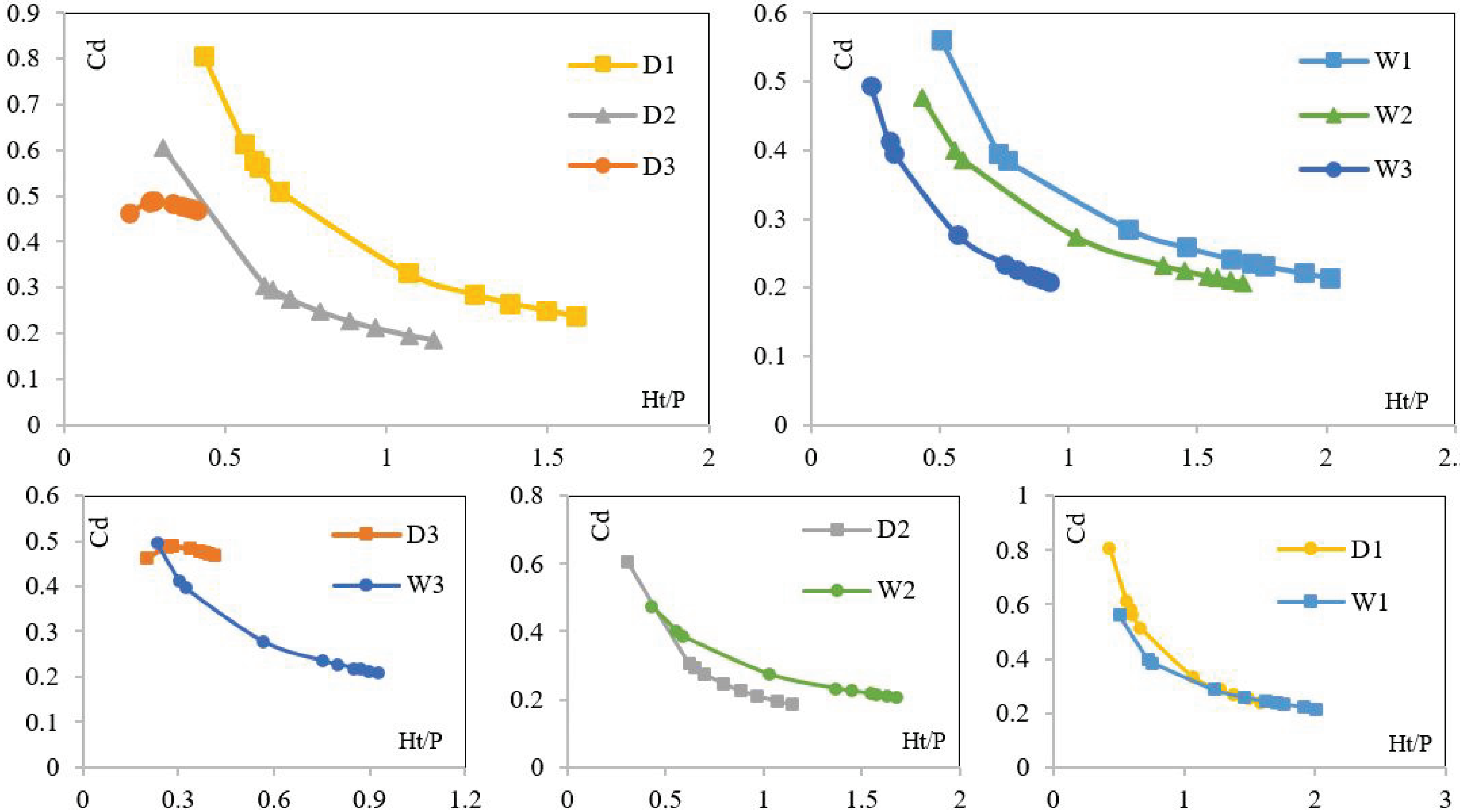


Figure 4. Linear and Roller Spillway

As shown in Figure 4, the shape and height of the spillway affect the discharge coefficient. Specifically, with a 130% reduction in spillway height, the discharge coefficient increases by up to 70% for the linear spillway and up to 90% for the roller spillway. Additionally, as the spillway height decreases, the performance of the roller spillway is better compared to the simple linear spillway, which can be attributed to the improved stream over the roller spillway. The shape of the spillway also influences efficiency, such that at a fixed height (6.5 cm), the roller spillway increases the discharge coefficient by up to 25% compared to the linear spillway. Comparing these two spillway models indicates that the roller spillway enhances performance.

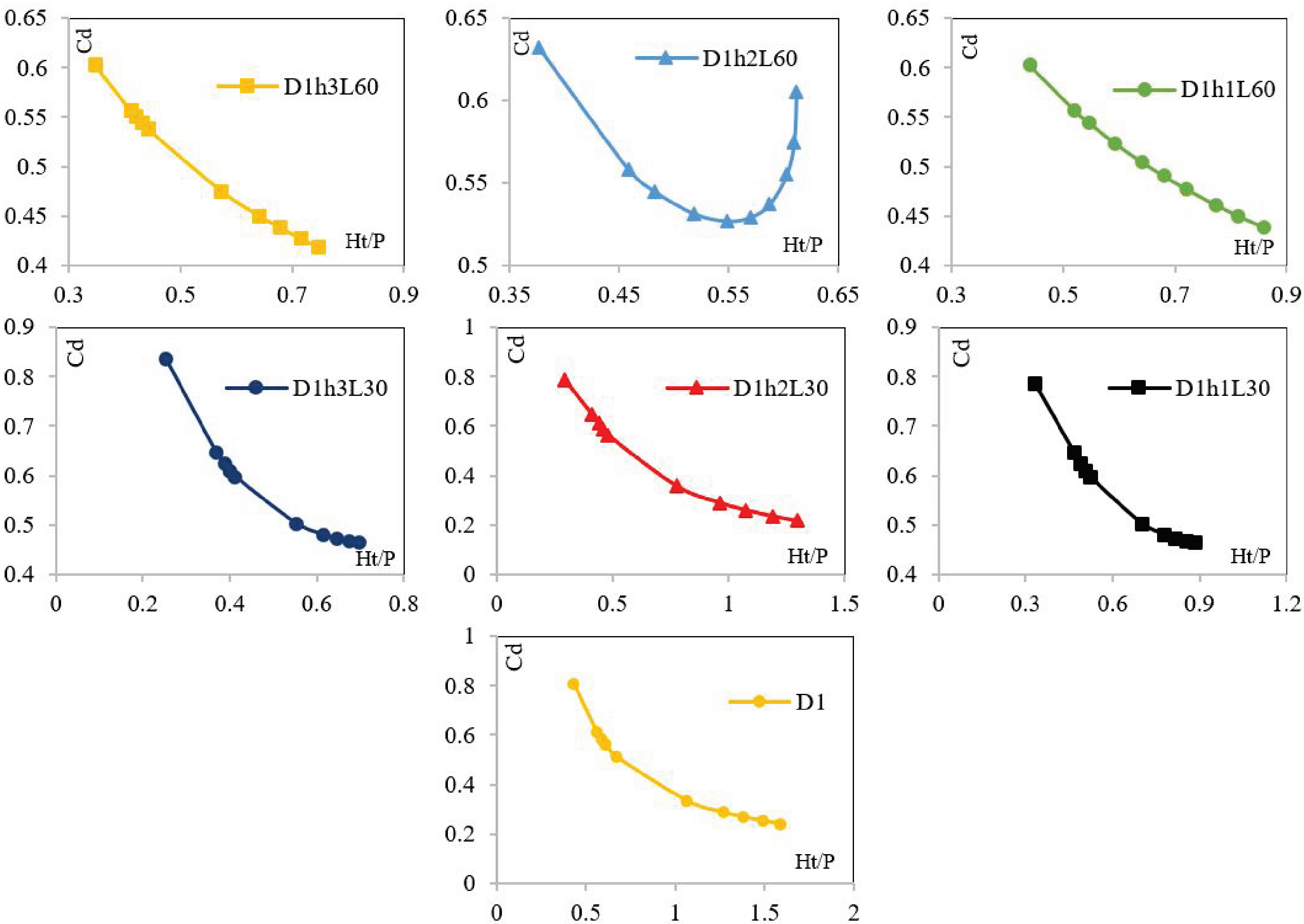


Figure 5. Effect of Ht/P on the Discharge Coefficient (Cd) in Roller Spillway D1

Figure 5 illustrates the impact of full and half blades on the roller spillway with a diameter of 6.5 cm. This graph indicates that installing a blade on the roller spillway increases efficiency, as the installation of a half blade (30 cm long) leads to a 27% increase in efficiency, while the installation of a full blade (60 cm long) results in an 8% decrease in efficiency. Additionally, there is a 38% difference in efficiency between the half blade and the full blade at a fixed blade height, with the half blade demonstrating better performance than the full blade.

Tecnología y Ciencias del Agua
OPEN ACCESS
Check for updates

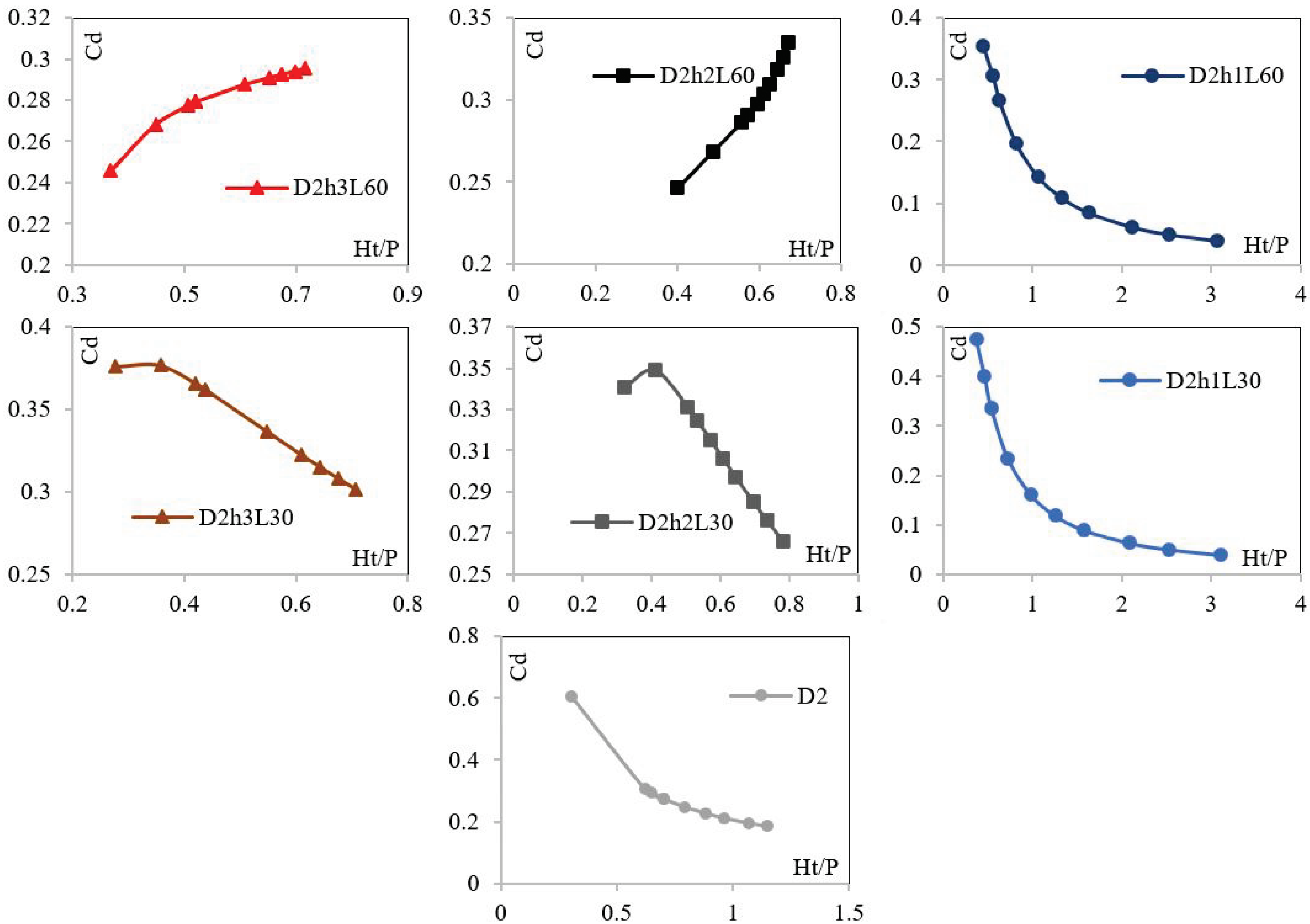


Figure 6. Effect of Ht/P on the Discharge Coefficient (Cd) in Roller Spillway D2

Figure 6 shows the impact of full and half blades on the roller spillway with a diameter of 7.0 cm. This graph reveals that installing a blade on the roller spillway decreases efficiency, as the installation of a half blade (30 cm long) results in a 25% decrease in efficiency, while the installation of a full blade (60 cm long) leads to a 68% decrease.

Tecnología y Ciencias del Agua

OPEN ACCESS

Check for updates

Furthermore, there is a 40% difference in efficiency between the half blade and the full blade at a fixed blade height, with the half blade again showing better performance.

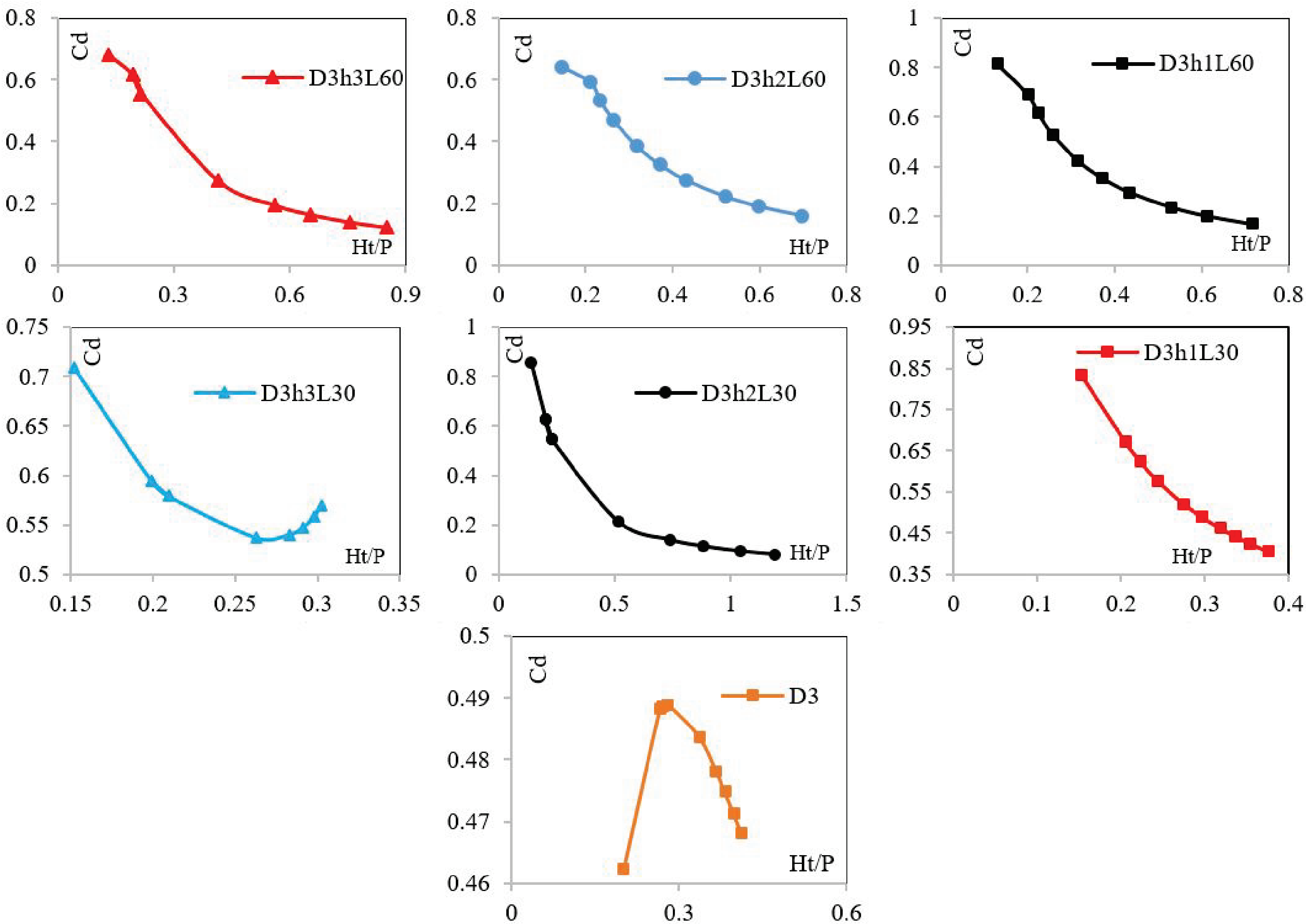


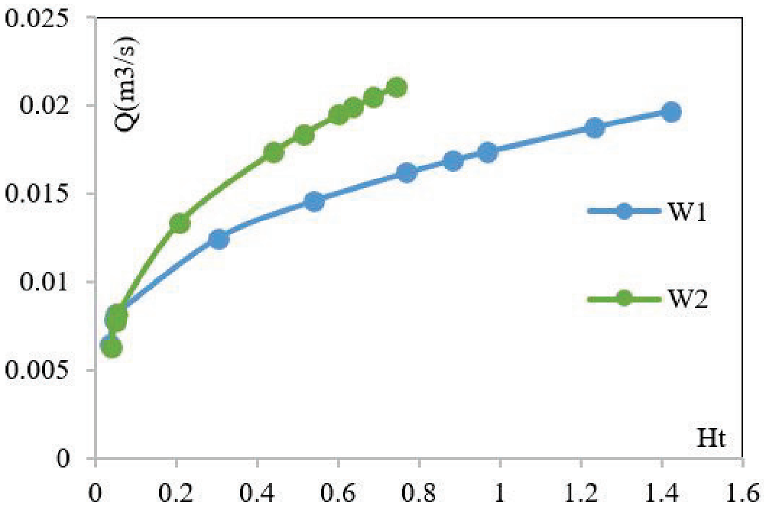
Figure 7. Effect of Ht/P on the Discharge Coefficient (Cd) in Roller Spillway D3

Figure 7 illustrates the impact of full and half blades on the roller spillway with a diameter of 16 cm. This graph indicates that installing a blade on the roller spillway increases efficiency, with a half blade (30 cm long) leading to a 70% increase in efficiency and a full blade (60 cm long) leading to a 62% increase. Moreover, there is a 5% difference in efficiency between the half blade and the full blade at a fixed blade height, with the half blade demonstrating better performance than the full blade.

Based on Figures 4 to 7, it can be concluded that a roller spillway with a half-width blade can increase the efficiency of the spillway by up to 95% compared to a simple linear spillway. Moreover, the half blade shows better performance than the full blade, which can be explained by the fact that installing a full blade effectively turns the roller spillway into a simple linear spillway, thereby reducing efficiency in the linear spillway. In contrast, the half blade, which occupies half the width of the linear spillway and has the other half shaped as a semicircle, allows the roller spillway to perform better.

3.2. Flow rate-water load curves

In this section, we examine the impact of the roller spillway on the output discharge under a constant water load.



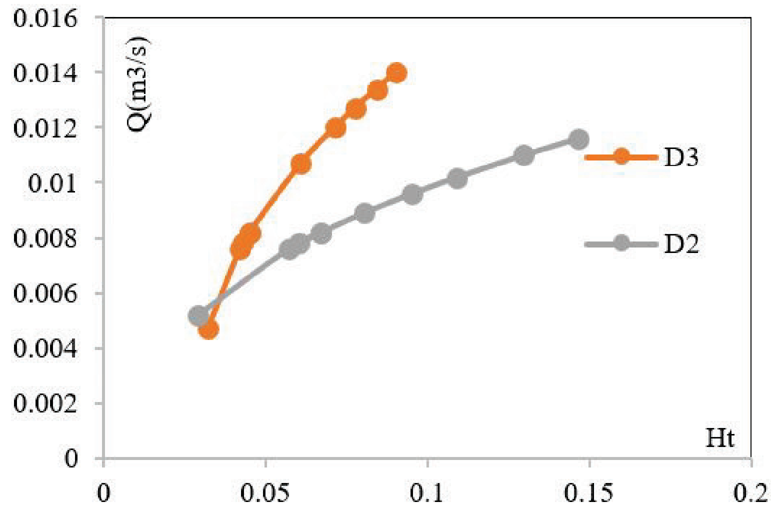


Figure 8. Flow rate-water Load Curve for Linear and Roller Spillways

Figure 8 shows the flow rate-water load curve for simple linear and roller spillways. At a fixed water height over the spillway crest, the roller spillway can pass a greater flow rate, such that at a water head of 0.5 meters, the linear spillway passes up to 80% less discharge. However, at a constant flow rate, for example, 0.01 cubic meters per second, the water height over the roller spillway crest is up to 200% lower than that of the linear spillway, indicating that the roller spillway facilitates stream passage more easily.

Tecnología y ciencias del agua, ISSN 2007-2422,
DOI: 10.24850/j-tyca-18-01-02

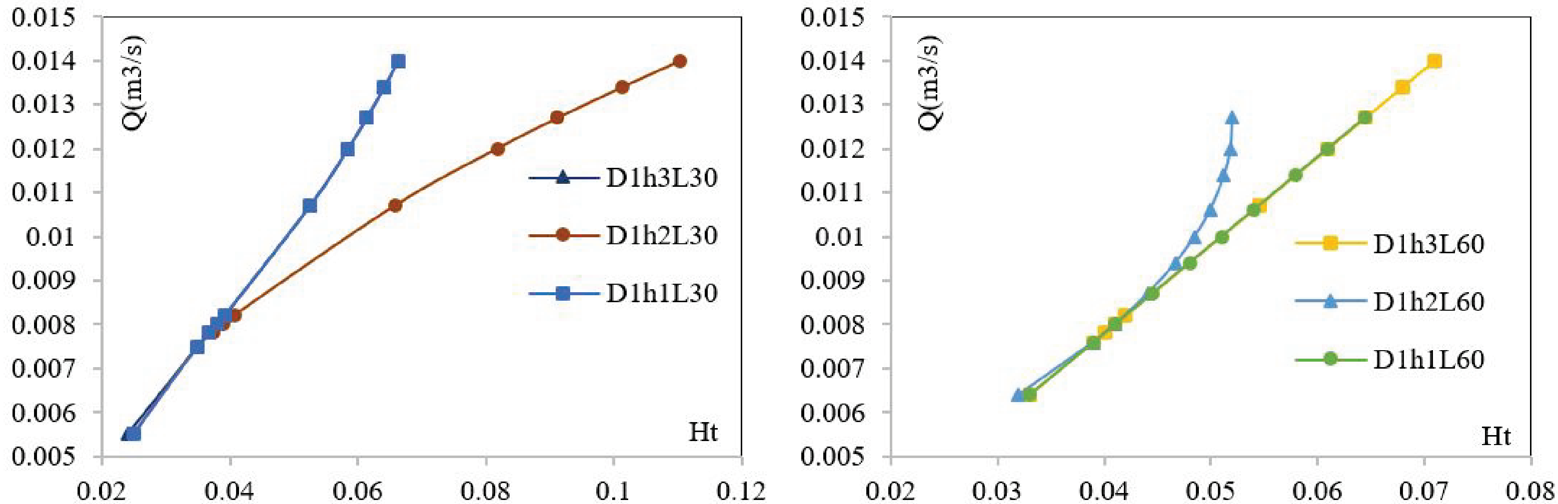


Figure 9. Stage flow rate curve in the roller spillway D1

Figure 9 illustrates the stage flow rate for roller spillways with a diameter of 6.5 cm with blades. At a fixed water height over the roller spillway crest, the half-blade roller spillway can pass a greater discharge, such that at a water head of 0.4 meters, it passes up to 10% more flow rate than the linear spillway. However, at a constant flow rate of 0.01 cubic meters per second, the half-blade roller spillway has a water height over its crest that is 9% higher than that of the full-blade roller spillway.

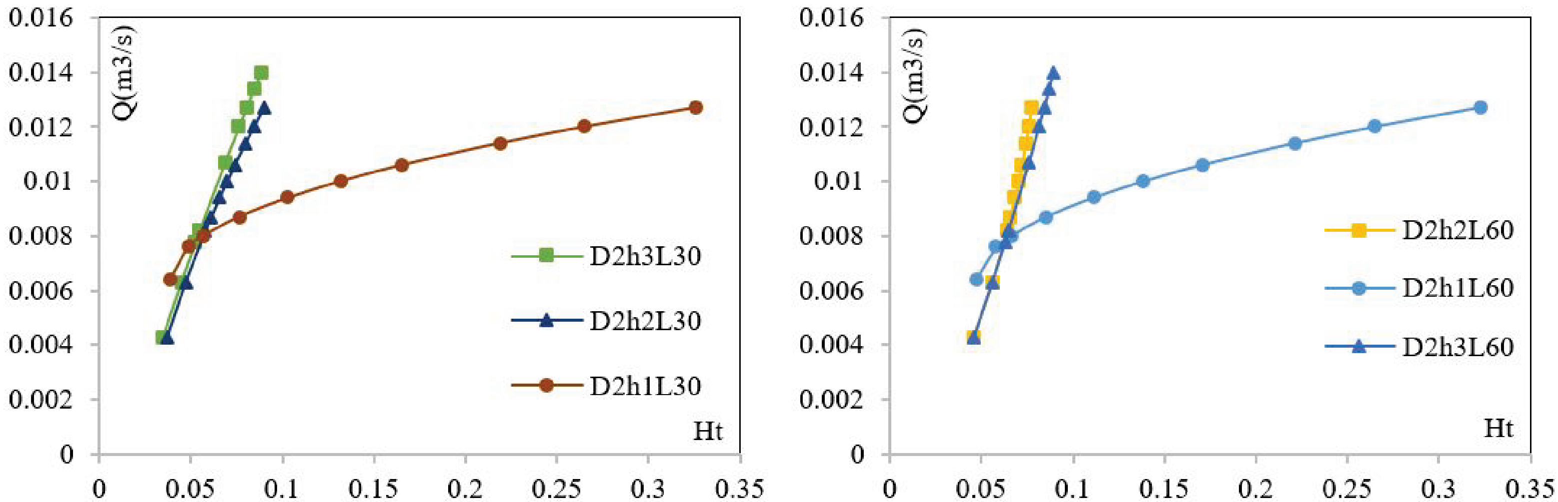


Figure 10. Stage flow rate curve in the roller spillway D2

Figure 10 shows the stage flow rate curve for roller spillways with blades with a diameter of 7.0 cm. There is not much difference between the half-blade and full-blade performance.

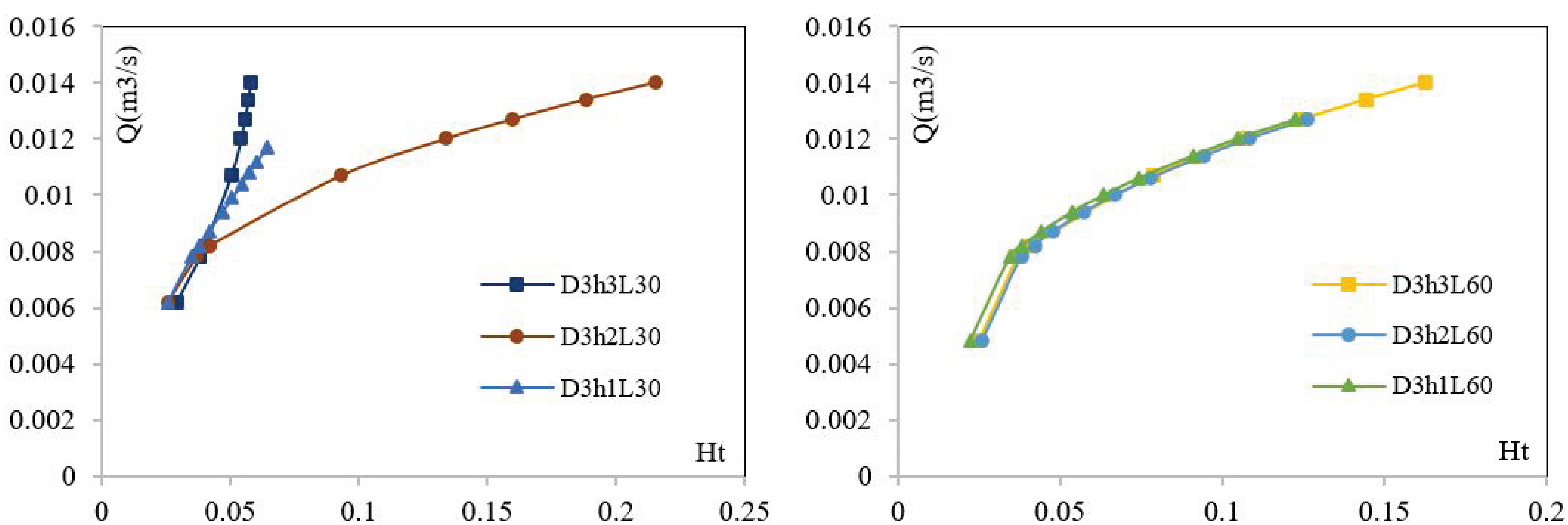


Figure 11. Stage flow rate curve for roller spillway D3

Tecnología y ciencias del agua, ISSN 2007-2422,
DOI: 10.24850/j-tyca-18-01-02

In the Figure 11, which illustrates the stage flow rate curve for roller spillways with a diameter of 16 cm with blades, at a fixed water height over the crest of the roller spillway, the half-blade roller spillway can pass a greater flow rate, such that at a water head of 0.5 meters, it passes up to 60% more discharge than the linear spillway. However, at a constant flow rate, for example, 0.01 cubic meters per second, the water height over the crest of the half-blade roller spillway is up to 40% lower than that of the full-blade roller spillway. From the graphs in Figures 8 to 11, it can be concluded that the roller spillway allows water to stream more easily over it, and at a constant flow rate, due to the shape of the crest, it can facilitate faster water passage, which in turn increases the efficiency of the discharge coefficient in the roller spillway compared to the linear spillway.

3.3. Practical Implications of Results

The results obtained in this study are presented in dimensionless form (Ht/P and Cd), which allows their application to prototype-scale structures through hydraulic similarity principles. Similar approaches have been widely used in spillway design and analysis (Singh and Kumar, 2022). The observed increase in discharge coefficient (up to 70%) implies that, for a given discharge, the required crest length or spillway width can be significantly reduced. This finding is consistent with previous studies on nonlinear and labyrinth spillways, where geometric modification leads to improved hydraulic performance (Muhamad, 2024; Ghanbari et al., 2020).

From an engineering perspective, this improvement can lead to reduced construction costs and enhanced discharge capacity, particularly in cases where space limitations restrict spillway width expansion (Gubashi et al., 2024; Kumar et al., 2020).

4. Conclusion

A spillway is a structure for controlling the height and flow rate, used in dams and channels. The efficiency of this structure enhances its lifespan and reduces operational costs. In this research, we examined the impact of a new model of spillway called a roller on efficiency. Additionally, a blade-like structure was installed across the roller spillway, leading to the following results:

As the height of the spillway decreases, the discharge coefficient increases, such that a 128% reduction in the height of the roller spillway results in a 30% increase in the discharge coefficient.

The shape of the spillway enhances efficiency, with the roller spillway increasing efficiency by up to 30% at similar heights.

A full blade reduces efficiency by 3% compared to the roller spillway without a blade in the D1 configuration, while a half blade (30 cm wide) installed on the roller spillway increased efficiency by up to 30%.

The blade in the roller spillway D2 causes a 50% reduction in efficiency.

The half blade in the roller spillway D3 increases efficiency by up to 70%, while the full blade increases it by up to 60%.

In addition to the experimental findings, this study demonstrates the practical applicability of Roller spillways in real hydraulic engineering projects. The key conclusions are:

- Roller spillways can significantly improve discharge efficiency (up to 70%), which can reduce spillway width and construction costs.
- The use of dimensionless parameters ensures that the results can be applied to prototype-scale structures.
- Roller spillways can enhance dam safety by increasing discharge capacity and reducing upstream water levels during floods.
- Partial blade configurations provide optimal performance and can be considered in practical design.

5. Discussion

The results of the present study provide clear evidence that modifying the crest geometry from a conventional linear shape to a cylindrical Roller configuration significantly enhances the hydraulic performance of spillways. This improvement is primarily reflected in the increase of the discharge coefficient (Cd), which in some configurations reached values up to 70% higher than those of traditional linear spillways. Such an increase is not only statistically meaningful but also highly relevant from an engineering design perspective (Gharibvand et al., 2020; Gubashi et al., 2024).

One of the key aspects of this study is that the analysis was conducted using dimensionless parameters such as Ht/P and Cd. This approach allows the findings to be extended beyond laboratory scale and applied to prototype conditions with a reasonable degree of confidence. In practical terms, an increase in Cd implies that, for a given discharge, a smaller crest length or spillway width is required. This can lead to substantial savings in construction costs, especially in large-scale hydraulic structures such as dams, where spillway dimensions directly affect excavation volume and structural materials (Singh and Kumar, 2022; Razmkah et al., 2021).

From a hydraulic standpoint, the improved performance of the Roller spillway can be attributed to the smoother flow transition over the cylindrical crest. Unlike sharp-crested or linear spillways, where flow separation and turbulence are more pronounced, the Roller geometry appears to guide the flow more gradually, reducing energy losses and promoting more stable flow conditions. This observation is consistent with the reduced upstream head required to pass the same discharge, as observed in the stage–discharge relationships (Pashazadeh et al., 2016; Ghanbari and Heidarnejad, 2020).

The role of blade installation on the Roller spillway presents an interesting and somewhat nuanced behavior. While the addition of a blade might be expected to enhance flow control, the results indicate that its effectiveness depends strongly on its length and configuration. In particular, the half-length blade consistently outperformed the full-length blade in several cases. A possible explanation is that the full blade alters the flow pattern in a way that partially negates the beneficial curvature of the Roller crest, effectively making the flow behave more like that over a linear spillway. In contrast, the half blade allows part of the flow to benefit from the curved geometry while still introducing localized flow guidance, resulting in an optimal balance between control and efficiency (Muhamad, 2024; Gubashi et al., 2024).

When considering real-world applications, these findings are particularly relevant for situations where spillway capacity is constrained by geometric or economic limitations. In many existing dams, increasing spillway width is not feasible due to site constraints or high retrofit costs.

In such cases, adopting a Roller spillway configuration could provide a practical alternative for increasing discharge capacity without significant structural modification (Derakhshanifard et al., 2023; Kumar et al., 2020). Furthermore, the reduction in upstream water level for a given discharge can contribute to improved dam safety during extreme flood events (Saghari et al., 2019; Gharibvand et al., 2016). It is also worth noting that Roller-type spillways have already been implemented in specific cases, such as the Roza Dam in the United States, although their primary purpose in that context was related to ecological considerations. The present study complements such applications by providing a detailed hydraulic analysis and demonstrating that these structures can also offer significant advantages in terms of flow efficiency (USBR, 2010).

Despite these promising results, some limitations should be acknowledged. The experiments were conducted under controlled laboratory conditions with a fixed channel slope and limited range of geometric parameters. Therefore, further research is recommended to investigate the performance of Roller spillways under varying slopes, sediment conditions, and larger scale models. Additionally, numerical simulations could complement the experimental findings and provide further insight into flow patterns and energy dissipation mechanisms (Gubashi et al., 2024; Singh and Kumar, 2022).

Overall, the findings of this study suggest that Roller spillways represent a viable and potentially advantageous alternative to conventional linear spillways. Their ability to enhance discharge capacity, reduce upstream head, and optimize structural dimensions makes them a promising option for both new designs and the rehabilitation of existing hydraulic infrastructure (Hamidinia et al., 2023; Ghanbari and Heidarnejad, 2020).

6. References

Afzalian, A., & Ahadian, J. (2016). Piano Key Weirs with Positive Parapet Wall. *Water and Soil Science*, 25(4/2), 97-107. https://doi.org/10.1080/23570008.2023.2210391

Aghashirmohammadi, G., Heidarnejad, M., Purmohammadi, M. H., & Masjedi, A. (2023). Experimental and numerical study of the effect of flow splitters on trapezoidal and triangular labyrinth weirs. *Water Science*, 37(1), 28–39. https://doi.org/10.1080/23570008.2023.2210391

Ariyamanesh A., & Heidarnejad M. (2020) Laboratory investigation of the discharge coefficient of triangular labyrinth weirs with and without slots and comparing them with piano key weirs. *Irrigation and Drainage*, 69 1167–1175. https://doi.org/10.1002/ird.2509

Asghari Pari, S. AM., Razmkhah, A., Asghari Pari, S. AL., & Kordnaeij, M. (2023). Experimental Study of the Effect of the Location of a Continuous Porous Obstacle on the Bottom of a Stepped Spillway on the Characteristics of the Flow. *Water Resources Engineering*, *16*(56), 79-94. https://doi.org/10.30495/wej.2023.28972.2338

Derakhshanifard, M., Heidarnejad, M., Masjedi, A., Bordbar, A., & Egdernezhad, A. (2023). Experimental Study of Effect of Creating an Additional Cycle along the Lateral Crest of the Labyrinth Weirs. *Flow Measurement and Instrumentation*, 90, 102306. https://doi.org/10.1016/j.flowmeasinst.2023.102306

Eslinger, K., & Crookston, B. M. (2020). Energy Dissipation of Type a Piano Key Weirs. *Water*, *12*(5), 1253. https://doi.org/10.3390/w12051253

Ghanbari, R., & Heidarnejad, M. (2020). Experimental and numerical analysis of flow hydraulics in triangular and rectangular piano key weirs. *Water Science*, 34(1), 32–38. https://doi.org/10.1080/11104929.2020.1724649

Gharibvand R., Heidarnejad M., Kashkouli H A., Hasoonizadeh H., & Kmanbedast A. (2020). Numerical Analysis of Flow Hydraulic in Trapezoidal Labyrinths and Piano Key Weirs. *Journal of Water and Soil Science*, 24 (1), 45-56. https://doi.org/10.47176/jwss.24.1.38092

Ghasemi Ghasemvand, R., Heidarnejad, M., Masjedi, A., & Bordbar, A. (2024). Experimental study of hydraulic losses in linear and nonlinear weirs: A comparative analysis. *Water Science*, 38(1), 378–390. https://doi.org/10.1080/23570008.2024.2373954

Gubashi, Karim & Mulahasan, Saad & Hacheem, Zuhair & Rdhaiwi, Ali. (2024). Effect of the Stepped Spillway Geometry on the Flow Energy Dissipation. *Civil Engineering Journal*, 10, 145-158. https://doi.org/10.28991/CEJ-2024-010-01-09

Hamidinia, M., Heidarnejad, M., Pourmohammadi, M. H., & Masjedi, A. (2023). Investigation of the effect of increasing the height of the side wall on the performance of nonlinear weirs. *Water Science*, 37(1), 304–314. https://doi.org/10.1080/23570008.2023.2245245

Iranpour, A., Egdernezhad, A. & Heidarnejad, M. (2024). Numerical Investigation of Energy Dissipation in Baffled Piano Key Weirs. *Journal of New Approaches in Water Engineering and Environment*, *3*(1), 55-70. https://doi.org/10.22034/nawee.2024.451817.1069

Kumar, M., Sihag, P., Tiwari, N. K., & Ranjan, S. (2020). Experimental study and modelling of discharge coefficient of trapezoidal and rectangular piano key weirs. *Applied Water Science*, 10, 43. https://doi.org/10.1007/s13201-019-1104-8

Bashar, N.A.M., Zainol, M.R.R.M.A., Aziz, M.S.A., Zawawi, M.H., Mazlan, A.Z.A. (2024). Hydraulic Properties of Flow Over Different Types of Spillways: A Review. In: Sabtu, N. (eds) *Proceedings of AWAM International Conference on Civil Engineering* (Vol. 3). Springer. https://doi.org/10.1007/978-981-99-6026-2_50

Pashazadeh M., Heydarpour M., Saghaeian Nejad M., & Razavian H (2017). Investigation of Simultaneous Flow under Sluice Gate and over Trapezoidal Weir in Circular Channel. *Irrigation and Drainage Structures Engineering Research*, *17*(67), 70-80. https://doi.org/10.22092/aridse.2017.109615

Saghari A, Saneie M, Hosseini K (2019) Experimental study of one-and two-cycle trapezoidal piano-key side weirs in a curved channel. *Water Supply*, 19 1597–1603. https://doi.org/10.2166/ws.2019.029

Singh D, Kumar M. (2022) Hydraulic Design Analysis of Piano Key Weirs: A Review. *Arabian Journal for Science and Engineering*, 47, 5093–5107. https://doi.org/10.1007/s13369-021-06370-4

USBR, U.S. Bureau of Reclamation (2010). *Reclamation managing water in the west. Roza Dam Evaluation Post Modifications*. U.S. Department of the interior, Bureau of Reclamation. https://dashboard.yakamafish-star.net/sites/default/files/2019-02/Larrick_2011_YBSMC.pdf